THE PHYSICAL SCIENCES: A CONTEMPORARY APPROACH

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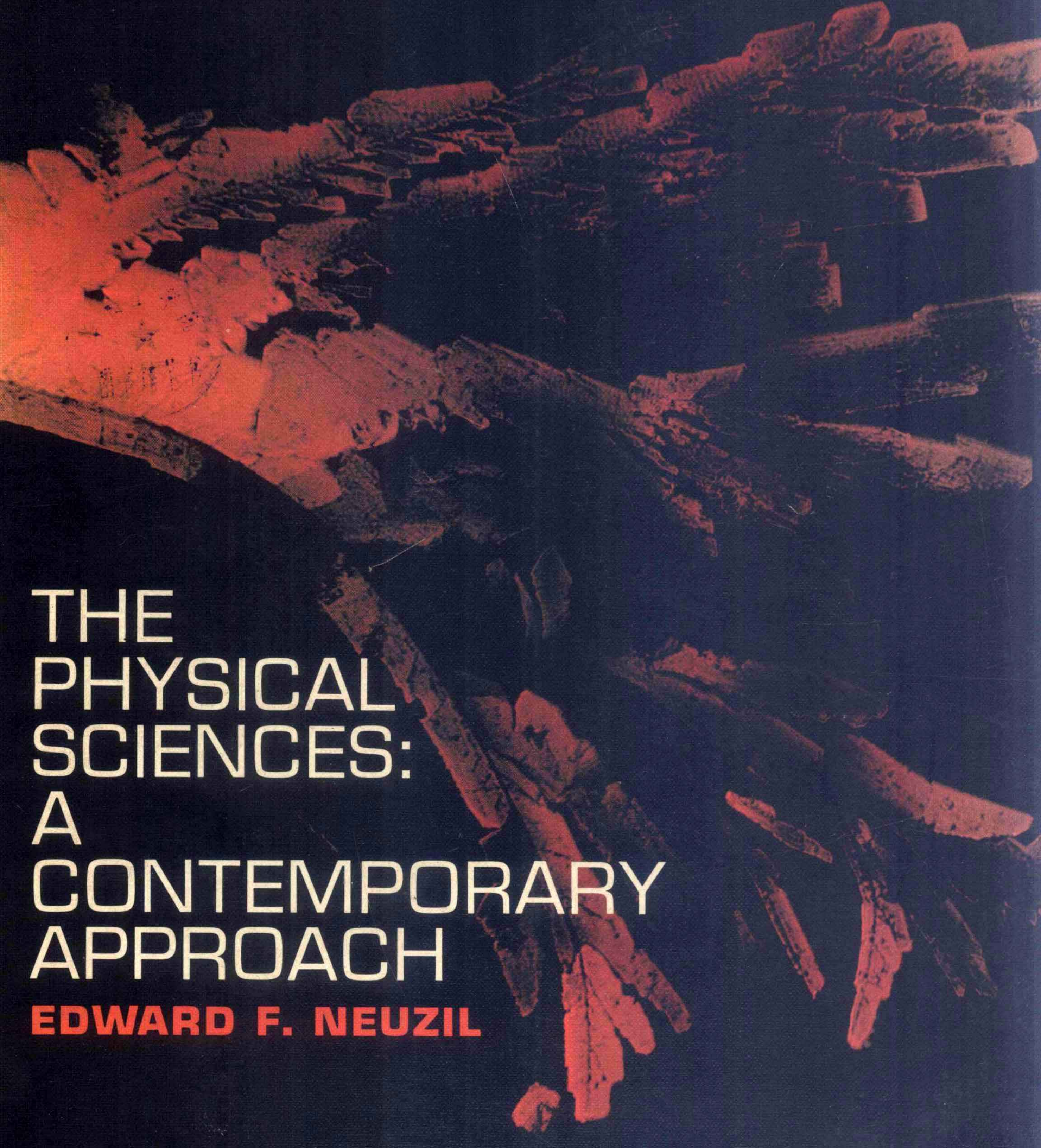

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PREFACE

This book was written for today's student. As such it is neither a collection of facts and mathematical proofs, nor a treatise on the history of science. Instead, it is an attempt to show that science depends on the orderly use of accumulated knowledge, to heighten the student's awareness of scientific achievement, and to relate this achievement to the student's world.

The contemporary student should understand how scientists verify and generalize their observations. Therefore, statements such as "the atom is made up of protons, neutrons, and electrons" are supported by explanations of how scientists have come to agree on such facts. However, rigorous mathematical proofs of physical theory are not given. Instead, we present, wherever possible, verbal and graphic explanations of theories. The development begins with simple arithmetic operations and an introduction to the standard units of measure, then moves on to an analysis of motion, to concepts of energy, to a study of electricity and magnetism, and finally, to an explanation of the development of *models* of atoms and molecules. After mastering this fundamental knowledge, the student is prepared to study the variety of subjects that follow: biochemistry, earth science, oceanography, and space.

A discussion of modern scientific developments is included in the belief that they are as important to the student's understanding of science as Newton's laws. Therefore, such topics as relativity, quantum mechanics, phosphorescence, semiconductors, transistors, DNA, quasars, modern theories of the origin of the ice ages, and continental drift are covered.

Man's use of science has shaped and misshaped the contemporary world. To alert students to this dual aspect of scientific progress, Interchapter Summary 5 deals specifically with the interaction of man, science, and the environment by discussing air and water pollution. Throughout the text, wherever appropriate, environmental problems such as drugs, radioactive fallout, the long-term effects of insecticides, and fertilizers are discussed.

Questions appear at the end of each chapter. Most require verbal answers; some reflect scientific precision by yielding precise numerical answers; some are philosophical, and others, by having no pat answers, show that science has not answered all questions precisely. Throughout the text, many worked-out examples are given. As in the problems, some of these examples have numerical solutions and others require verbal answers.

This book is designed for college physical science courses. There is enough material here to enable an instructor to choose whatever material suits his particular needs or interests. Prerequisites for study of the text are few. In almost every case, no knowledge of high school science is assumed. Mathematics, when used, is simple algebra and may be omitted in favor of the verbal and graphic arguments.

I wish to extend sincere appreciation to Mrs. Ann Drake and the Bureau for Faculty Research at Western Washington State College for their help in manuscript preparation. I am especially indebted to Professor Ross Ellis for his patience in reviewing the sections on geology, and to Professor Mel Davidson for his review of the physics sections. I am also appreciative of the assistance of U.S. Representative Lloyd Meeds in helping me obtain many government photographs used in the text. I also wish to express my gratitude to graduate students Bob Kieburtz and Bob Williams for reading the galleys and checking the many problems. And finally, I extend my apologies to those students who feel that I have not measured up to their expectations.

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The importance of accurate knowledge . . . was foreseen long ago by Plato . . . "If from any art that which concerns weighing and measuring and arithmetic is taken away, how little is left of that art!"

THEODORE W. RICHARDS, 1914
Atomic Weights

CONTENTS

1

BASIC MEASUREMENTS, CALCULATIONS, AND PROPERTIES OF MATTER

THE WORK OF MAN

If we were to mention the names Shakespeare, Churchill, John Steinbeck, Kennedy, and James Baldwin, you would know that we were discussing the arts, literature, and those political achievements of man that you could readily understand and find very fascinating. However, if we were to substitute the names Archimedes, Newton, Gauss, Faraday, Einstein, Schrödinger, and Fermi, you would know that you were about to enter what you conceive to be the incomprehensible world of science. Furthermore, you would assume that it would be boring and uninspiring. But keep this one concept in mind as you undertake this task: like the works of Shakespeare and the others mentioned above, the achievements of science were not produced by any superhuman form, but by men who, like Shakespeare, had a gift with which to probe and shed light on the nature of the universe. And since these discoveries were made by human beings, it should be quite possible for us to understand them; if we cannot understand them in detail, at least we should understand the concepts these men of science have given us as part of our human heritage. Therefore, although we certainly do not know every episode in *Tom Sawyer* or *Hamlet,* or the complete history of the First World War, we do know or can learn the essentials of these affairs of man. Likewise, we will not be able to know all details of the First Law of Thermodynamics, of nuclear energy, or of relativity, but we can, as rational, intelligent human beings, understand the basic ideas behind these world-shaking and world-shaping concepts.

The problem of understanding scientific concepts revolves around the obstacle of speaking in two languages. One of the languages is, of course, our native tongue, and here there is no problem. But the second, yet universal, language is where the trouble begins: this is the language dealing with numbers and manipulation of numbers which we may, for the lack of a better term, call the language of mathematics. Many people avoid this subject and state many reasons why they cannot utilize this form of man's expressive nature. Their reasons may vary from poor preparation and instruction to a simple case of self-brainwashing. Whatever the cause or excuse, there should again be no reason why an endeavor of man cannot at least be basically understood by another person. This, then, is our task: to understand the basic scientific achievement of man, and in doing so, find that it is comprehensible and just as imaginative and exciting as man's art, history, or literature.

The task of a cave man trying to understand the night sky is not much different from our task today; we just have a better starting point. But as the cave man began, so we must begin at a rudimentary level and with the basic tools of science.

FUNDAMENTAL UNITS

Units of Mass. As the artist's tools are the brush, canvas, and paints, the novelist's tools the pen and paper, so too must the man of science have his tools. Basically, no matter how complex the scientific investigation of the universe may be, man may ask the question, "How much?" The next logical question would be "How much of what?"

Let us consider the matter further, using the same analogy. The dictionary defines science as "a branch of study concerned with observation and classification of facts." Thus, we must find a way to describe these facts. First, let us realize that in dealing with and understanding the physical universe, we are dealing with the basic constituent of the universe—MATTER. We will soon see that this simple word covers a very extended but ordered concept. Matter is the material out of which all of us and all of the universe is made. To understand the basic nature of matter we must begin our study on the simplest possible plane.

Let us start by the imaginative process of picking two rocks, the first one larger than the second. Now, observing the two rocks, we again ask the question, "How much of what?" Here we make use of our first tool or operation in scientific investigation: *the definition.* We must define the two objects as rocks. We would then be forced into a further detailed set of criteria which we must assign to our specimens to make it quite clear what we mean by a rock; the more we knew about the rock the more detailed our description would become. Eventually, we would establish a new branch of science called geology. However, for our simple needs we may define a rock as any hard, compact piece of earth matter of irregular shape. But now we must tackle the question, "How much rock?" We must now define a new term to represent *how much matter* we have. The term we shall use is called *mass.* Obviously, the larger rock of the two (if they are the same kind of rock) has more mass. How much more? Here we must begin to assign numbers to represent the amount of mass we are speaking of. We need some system by which we can compare amounts of mass (or amounts of matter). But how do we compare if we have not yet stated what we are comparing to? It is obvious that we need a *standard reference mass.*

Early attempts to produce a standard mass reference were surely quite crude, and some still exist today. For example, in England mass (or weight—we shall describe the difference in terms later) is recorded in stones! Imagine weighing two stones, four pebbles, and three grains! It makes no difference what we measure in science, we must always do so by referring to a standard which is an arbitrarily accepted standard, usually determined by an international agreement. We do this by selecting a chunk of matter, let us say a block of platinum* metal, calling it one unit of mass, and then requiring that all masses be compared to it. But the phrase "one unit of mass" is awkward, hence we have developed the so-called *English unit of mass, the pound,* or the more versatile unit of the *metric system* called the *kilogram* (1000 grams). Table 1–1 indicates the units of mass of the English and metric systems of masses. Note that the masses in both systems are expanded to smaller and larger units of mass. The metric system is very much easier to use since, like the American monetary system, it is in units of ten.

TABLE 1-1

ENGLISH AND METRIC UNITS OF MASS

English units	*Metric units*
1 lb = 16 oz	1 kg = 1000 g
2000 lb = 1 ton	1000 kg = 1 metric ton
1 lb = 454 g	1 g = 1000 mg (milligrams)
	1 g = 5 metric carats

Interconversion factors

1 lb = 454 g
1 kg = 2.21 lb
1 g = 0.0353 oz
1 g = 0.00221 lb

Now that we have defined our mass and its standard unit we shall, as shown in Table 1–1, give an abbreviated symbol for the concept of mass; we shall use the symbol m to represent mass. But how do we compare objects of different masses? We shall see later when we speak of the earth's gravity that objects are held to the earth's surface by the gravitational attraction of objects to the earth. The magnitude of the pull of objects toward the earth is called the weight of the object. The more massive the object the greater the gravitational pull, hence the greater the weight. Far before recorded history man developed a way of comparing the masses of different objects by utilizing this gravitational pull even though he had no idea of the concept of gravity. He simply balanced one object against the standard reference masses (this is shown in Figure 1–1). A one-pound (1-lb) object is balanced from a point (called a fulcrum) equidistant from two equal mass-accepting

* Stored at the International Bureau of Weights and Measures in France.

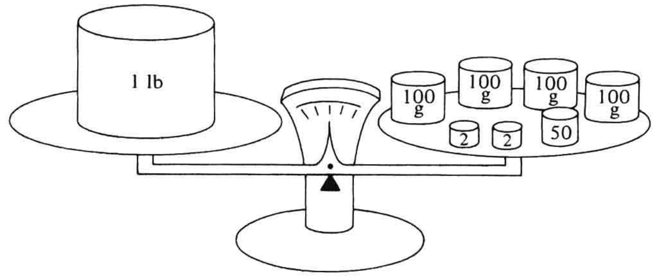

FIGURE 1–1 Balancing a 1-lb object in gram masses.

pans; the object to be weighed is placed in one, and the standard reference weights are added to the other. When the masses on each side balance, the amounts of standard mass units used are totaled to obtain the mass of the unknown object. Given below are some sample weighings in both the English and the metric systems. In addition, some sample problems of interconversion of English and metric systems are given. Be sure you notice that the arithmetic operations of numbers must also include the *label attached to the number.* This label is called the *dimension* of the number and states the units the number represents.

EXAMPLE 1–1

An English weighing

Pound units	2.0 lb
Ounce units	7.5 oz

Total mass 2.0 lb 7.5 oz

$$\text{or } 2.0 \text{ lb} + \frac{7.5 \text{ oz}}{16 \text{ oz/lb}}$$

$$2.0 \text{ lb} + \frac{7.5}{16} \cancel{\text{oz}} \frac{\text{lb}}{\cancel{\text{oz}}}$$

2.0 lb + 0.47 lb

2.47 lb

A metric weighing

Kilogram units	3.0000 kg
Gram units	250 g
Milligram units	150 mg

3.0000 kg + 0.250 kg + 0.000150 kg

3.250150 kg

or 3250.150 g

EXAMPLE 1–2

English units

Convert 5.0 lb 8 oz to ounces, read 16 oz per 1 lb

$$5 \cancel{\text{lb}} \left(\frac{16 \text{ oz}}{1 \cancel{\text{lb}}}\right) = 80 \text{ oz}$$

80 oz + 8 oz = 88 oz

Metric units

Convert 1.650 kg to grams and milligrams

$$1.650 \cancel{\text{kg}} \left(\frac{1000 \text{ g}}{1 \cancel{\text{kg}}}\right) = 1650 \text{ g}$$

$$1650 \cancel{\text{g}} \left(\frac{1000 \text{ mg}}{1 \cancel{\text{g}}}\right) = 1{,}650{,}000 \text{ mg}$$

EXAMPLE 1–3

English units Convert 2.5 kg to pounds	*Metric units* Convert 2.0 lb 8.0 oz to grams
$1.00 \text{ lb} = 454 \text{ gm}$	$8 \cancel{\text{oz}} \left(\frac{1 \text{ lb}}{16 \cancel{\text{oz}}}\right) = 0.50 \text{ lb}$
$1.00 \text{ lb} = 454 \cancel{\text{g}} \left(\frac{1 \text{ kg}}{1{,}000 \cancel{\text{g}}}\right)$	$2.0 \text{ lb} + 0.5 \text{ lb} = 2.50 \text{ lb}$
$1 \text{ lb} = 0.454 \text{ kg}$	$1 \text{ lb} = 454 \text{ g}$
$2.5 \cancel{\text{kg}} \left(\frac{1.00 \text{ lb}}{0.454 \cancel{\text{kg}}}\right) = 5.5 \text{ lb}$	$2.50 \cancel{\text{lb}} \left(\frac{454 \text{ g}}{1 \cancel{\text{lb}}}\right) = 1130 \text{ g}$

Note that the metric system is much more convenient; all you need to do to convert from one unit to another in the metric system is to slide the decimal point the appropriate number of spaces to the left or the right, as the case may be. However, in the English system the units of pounds and ounces are not in the decimal or base-ten system, but are based on a system of sixteen; that is, there are 16 oz to 1 lb. Also notice that the dimensions can be manipulated the same way as the numbers can. As in Example 1–3, the multiplication of 2.5 kg and the conversion factor 1 lb/0.454 kg, the units of kg cancel just as if they were identical numbers, as shown in Example 1–4.

EXAMPLE 1–4

$$\left(\frac{(2)(4)(3)}{1}\right)\left(\frac{6}{(4)(3)}\right) = \frac{(2)(\cancel{4})(\cancel{3})(6)}{(1)(\cancel{4})(\cancel{3})}$$

$$= \frac{2(6)}{1} = 12$$

$$\text{lb}\left(\frac{\text{kg}}{\text{lb}}\right)\left(\frac{\text{g}}{\text{kg}}\right) = \frac{(\cancel{\text{lb}})\ (\cancel{\text{kg}})\ (\text{g})}{(\cancel{\text{lb}})\ (\cancel{\text{kg}})} = \text{g}$$

Symbolic conversion of lb to kg to g

Significant Figures. Finally, in any calculation, performing an arithmetic operation does not give complete accuracy automatically. As in Example 1–3, the multiplication of 2.50 lb by (454 g/1.00 lb) using the normal arithmetic operation yields 1135.0 g, but the determinations by actual weighing were only to three places (or three significant figures) in the 2.50 lb and three in

↑ ↑↑
1 2 3

the 454 g. Therefore, the answer cannot be valid to five significant figures
1 2 3 4 5
↓ ↓ ↓ ↓ ↓
(1135.0) since our initial measurements were not that accurate. We are therefore required to "round off" the calculated value to three significant figures, or 1130 g, where the last zero simply represents the units of one place holder (actually the fourth number, 5, could have been rounded off in either direction; either 1140 g or 1130 lb). A further explanation of significant figures is found in Appendix I. However, a simple rule for us to follow would be that no arithmetic answer can be any more accurate than the least accurate measurement used to determine that answer. This is shown in Example 1–5.

EXAMPLE 1–5

(a) 2.5 (6.321) = 16

(b) $\dfrac{0.635}{2.6982} = 0.236$

(c) 1.693 g − 0.26 g = 1.43 g (only accurate to 0.01 g)

Units of Length or Distance. The first unit of measurement we described was mass (m), which usually has the dimensions of grams (g) or kilograms (1000 g = 1 kg), or pounds (1 lb = 454 g). The second unit of "how much" that man found essential in his trek toward civilization was the unit of length (l). Here again an arbitrary standard must be developed, and naturally a variety of units have cropped up. We can mention the strange units of rods, furlongs, shoe sizes, and so on to see the need for a good standard. Table 1–2 gives the diverse English system and the base-ten system of the more reasonable metric system. The standard unit of the metric system, the centimeter (cm), was for many years described as one one-hundredth of the length of the International Proto Meter stored at a fixed temperature (we shall describe temperatures later) which was the distance between two lines on a precious metal alloy bar in Paris, France. The new meter standard is defined by the properties of light, of which we will speak later. In the case of the standard meter, for example, the distance between the two inscribed lines is divided into 100 equal parts called centimeters (cm) and each centimeter is divided into 10 equal parts called millimeters (mm).

A comparison of the English and metric system is shown in the actual scale in Figure 1–2. Examples of each system and the interconversion of the units will be given later.

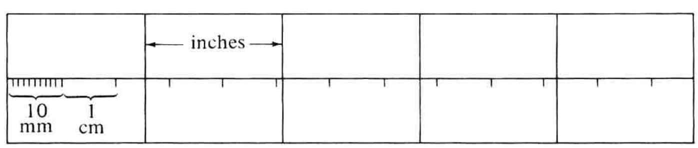

FIGURE 1–2 Comparison of rulers showing English and metric scales.